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METHOD, CHEMISTRY, AND APPARATUS FOR NOBLE METAL ELECTROPLATING ON A MICROELECTRONIC WORKPIECE

BACKGROUND OF THE INVENTION

The present invention is directed to electroplating a low-stress noble metal film onto the surface of a workpiece, such as a semiconductor wafer, in the manufacture of microelectronic devices and/or components. More particularly, the present invention is directed to a method, chemistry and apparatus for electroplating a noble metal, such as platinum, on a microelectronic workpiece.

Production of semiconductor integrated circuits and other microelectronic devices from workpieces, such as semiconductor wafers, typically requires formation of one or more metal layers on the workpiece. These metal layers are used, for example, to electrically interconnect the various devices of the integrated circuit. Further, the structures formed from the metal layers may be elements of microelectronic devices such as read/write heads, etc..

The microelectronic manufacturing industry has applied a wide range of metals to form such structures. These metals include, for example, nickel, tungsten, solder, and copper. Further, a wide range of processing techniques have been used to deposit such metals. These techniques include, for example, chemical vapor deposition (CVD), physical vapor deposition

(PVD), electroplating, and electroless plating. Of these techniques, electroplating tends to be the most economical and, as such, the most desirable. Electroplating can be used in the deposition of blanket metal layers as well as selectively deposited or patterned metal layers.

One of the process sequences used in the microelectronic manufacturing industry to form one or more metal structures on a semiconductor wafer is referred to as "damascene" or "inlaid" processing. In such processing, holes, commonly called "vias", trenches and/or other microscopic-sized recesses are formed in a workpiece surface and filled, either entirely or only partially, with a metal. In the damascene process, the wafer is first provided with a metallic seed layer which is used to conduct electrical current during a subsequent metal electroplating step. When certain metals that readily migrate into the surface of the wafer are used, the seed layer is disposed over a barrier layer material, such as Ti, TiN, Ta, TaN, etc.

The seed layer is a very thin layer of metal which can be applied using one or more of several processes. For example, the seed layer can be laid down using physical vapor deposition (PVD) or chemical vapor deposition (CVD) processes to produce a layer on the order of 100 - 1,000 angstroms thick. The seed layer can be formed of copper, gold, nickel, palladium, platinum, or other metals compatible with the subsequently applied metal. The seed layer is formed over a surface which is convoluted by the presence of the vias, trenches, or other recessed device features.

A metal layer may then be electroplated onto the seed layer. The layer is plated to form an overlying layer, with the goal of providing a metal layer that either entirely or partially fills the trenches and vias.

After the blanket layer has been electroplated onto the semiconductor wafer, excess metal material present outside of the vias, trenches, or other recesses is removed. The excess plated material can be removed, for example, using chemical mechanical planarization, chemical etching, or plasma etching. Chemical mechanical planarization is a processing step which uses the combined action of a chemical removal agent and an abrasive which grinds and polishes the exposed metal surface to remove undesired parts of the metal layer applied in the electroplating step. The metal is removed to provide a resulting pattern of metal layer in the semiconductor integrated circuit being formed.

The electroplating of the semiconductor wafers takes place in a reactor assembly. In such an assembly an anode electrode is disposed in a plating bath, and the wafer with the seed layer thereon is used as a cathode. Preferably, only a lower face of the wafer contacts the surface of the plating bath. The wafer is held by a support system that also conducts the requisite electroplating power (e.g., cathode current) to the wafer. The support system may comprise conductive fingers that secure the wafer in place and also contact the wafer seed layer in order to conduct electrical current for the plating operation. One embodiment of a reactor assembly is disclosed in U.S.S.N.

08/988,333 filed September 30, 1997 entitled "Semiconductor Plating System Workpiece Support Having Workpiece - Engaging Electrodes With Distal Contact Part and Dielectric Cover."

An efficient process for electroplating of certain noble metals is desirable in those microelectronic applications in which nickel, copper, etc. are not the optimal metal. Such components include, for example, sensors (electrochemical or micro-mechanical), capacitor structures in memory cells, and some interconnects for microelectronic devices. One application in which electroplating of a noble metal onto a workpiece is particularly useful is in the fabrication of platinum electrodes for capacitors used, for example, in semiconductor memory devices. . The work function of platinum facilitates the formation of capacitor electrodes that exhibit enhanced electrical characteristics, including lower leakage currents and a higher breakdown voltage when compared to electrodes of other metals. The low leakage current minimizes the amount of charge lost between refresh cycles of, for example, dynamic memory cells including such capacitors. The higher breakdown voltage allows the capacitor to store a larger charge without significant current leakage. Consequently capacitors having smaller geometries are possible thereby allowing the formation of a greater number of capacitors upon a workpiece of a given size. Further benefits of platinum relate to the fact that it has a low propensity to react with other materials or oxidize and, as such, does not form an undesired oxide

film at its surface when it is exposed to the ambient environment. This can be important where processing steps subsequent to the plating of the platinum expose the workpiece to oxygen. Such exposure is possible if subsequent processing steps, for example, try the workpiece and expose it to oxygen, such as found in the ambient air.

Various platinum electroplating processes are known, though efforts have mainly been directed at development of an appropriate electroplating bath, and additives for the bath. For example, a process of electroplating a platinum-rhodium alloy on a metal substrate has been disclosed in U.S. Patent No. 4,285,784; and a procedure for electroplating platinum and platinum alloys involving use of an organic polyamine as a platinum complexing agent has been disclosed in U.S. Patent No. 4,427,502. Moreover, there have been some uses of platinum in semiconductor chip manufacture. For example, selective deposition of platinum on a conductive or semiconductive substrate was disclosed in U.S. Patent No. 5,320,978, and a method for depositing a coat of platinum on the surface of a silicon substrate by dipping the substrate into an aqueous solution of chloroplatinic acid and hydrofluoric acid was disclosed in U.S. Patent No. 3,963,523. Recently, noble metal plating on a pre-existing seed layer for the fabrication of electrodes for use in DRAM and FRAM was disclosed in U.S. Patent No. 5,789,320.

Several technical problems must be overcome in designing reactors used in the electroplating of semiconductor wafers with a noble metal, such as platinum. For example, most

noble metals tend to be deposited in a state of high film stress. This film stress is generally greatest at or near the point of contact where current is applied to the seed layer during the electroplating process. This stress can be detrimental to the function and reliability of the microelectronic components produced using these materials.

One factor affecting film stress is the occurrence of varying current densities that occur during the plating process while the workpiece is functioning as a cathode. In many reactors used to electroplate metals onto the surface of a semiconductor wafer, a small number of discrete electrical contacts (e.g., 6 contacts) are used to contact the seed layer about the perimeter of the wafer. Such discrete contacts ordinarily produce higher current densities near the contact points than at other portions of the wafer. This non-uniform distribution of current across the wafer, in turn, causes non-uniform deposition of the plated metallic material and, further, produces a substantial film stress near the contact locations. Such reactors are therefore not particularly well-suited for plating noble metals, such as platinum.

Another problem with electroplating of noble metals onto workpieces concerns efforts to prevent the electric contacts themselves from being plated during the electroplating process. Any material plated to the electrical contacts must be removed to prevent changing contact performance. However, noble metals such as platinum, unlike metals such as copper, cannot be reverse plated from the electrical contacts. Rather, any electrical contact that is plated with the

noble metal must be replaced if the plating process is to remain in a satisfactory working state.

The foregoing concern also applies to the use of current thieving in the electroplating process. Current thieving, effected by the provision of electrically-conductive elements other than those which contact the seed layer, can be employed near the wafer contacts to minimize non-uniformity of the deposited noble metal. The electrically-conductive elements are generally exposed to the electroplating solution and, as such, are plated with the noble metal during the electroplating process. The elements must therefore be replaced if the plating process is to remain in a satisfactory operational state. As a result, current thieving, while desirable to increase film uniformities, can be costly to implement.

When electroplating a noble metal such as platinum, it is desirable to prevent electroplating on any exposed barrier layer near the edge of the semiconductor wafer. Electroplated material may not adhere well to the exposed barrier layer material, and is therefore prone to peeling off in subsequent wafer processing steps. Further, metal that is electroplated onto the barrier layer within the reactor may flake off during the electroplating process thereby adding particulate contaminants to the electroplating bath. Such contaminants can adversely affect the overall electroplating process.

The specific metal used for the seed layer can also complicate the electroplating process. For example, certain seed layer metals have a relatively high electrical resistance. Still further,

some noble metals, such as platinum, have a high electrical resistance. As a consequence, use of the typical plurality of electrical wafer contacts (for example, six (6) discrete contacts) may not provide adequate uniformity of the plated metal layer on the wafer due to non-uniformities in the plating current that result from the high electrical resistance of the seed layer and/or noble metal layer (e.g., platinum).

Beyond the contact related problems discussed above, there are also other problems associated with electroplating reactors. As device sizes decrease, the need for tighter control over the processing environment increases. This includes control over the contaminants that affect the electroplating process. The moving components of the reactor, which tend to generate such contaminants, should therefore be subject to strict isolation requirements. To control film stress, optimal process parameters must be determined for parameters such as electrolyte temperature, flow rate, cathode current density, current waveform and electrolyte composition. Other factors that should be considered include uniformity of deposition thickness, film resistivity, surface roughness, micro-feature throwing power and particulate contamination.

Still further, existing electroplating reactors are often difficult to maintain. Such difficulties must be overcome if an electroplating reactor design is to be accepted for large-scale manufacturing.

The present inventors have recognized and addressed many of the foregoing problems

that exist in connection with the plating of noble metals, particularly platinum. To this end, they have developed an efficient method and production worthy apparatus for electroplating noble metals onto the surface of a workpiece, such as a semiconductor wafer. The disclosed method and apparatus provide for a suitable deposition rate, excellent film characteristics, and a reduction in the level of film stress that could otherwise result in cracking, delamination, or poor device reliability.

SUMMARY OF THE INVENTION

The present invention is directed to an improved electroplating method, chemistry, and production worthy apparatus for depositing noble metals onto the surface of the workpiece, such as a semiconductor wafer, pursuant to manufacturing a microelectronic device, circuit, and/or component. The reliability of the noble metal material deposited using the disclosed method, chemistry, and/or apparatus is significantly better than the reliability of noble metal structures deposited using the teachings of the prior art. This is largely attributable to the low stress of films that are deposited using the teachings disclosed herein. The metals, which can be deposited, include gold, silver, platinum, palladium, ruthenium, iridium, rhodium, osmium and alloys containing these metals.

In accordance with one aspect of the present invention, an apparatus for plating a noble metal on a microelectronic workpiece is disclosed that comprises a reactor chamber that contains an electroplating solution containing ions or complexes of the noble metal or noble metal alloy that is to be plated onto the workpiece. The apparatus also includes a workpiece support having a contact for providing electroplating power to a surface at a side of the workpiece that is to be plated. The contact electrically contacts the workpiece at a large plurality of discrete contact points and each of the contact points is isolated from exposure to the electroplating solution. To complete the electroplating cell, an anode is provided and the electroplating solution and is

spaced from the workpiece support within the reaction chamber.

In accordance with a further aspect of the present invention, a contact member for use in conducting electroplating power to a surface of a microelectronic workpiece that is to be electroplated with a noble metal is set forth. The contact member comprises a conductive member and a removable conductive surface material disposed about an exterior surface of the conductive member. The removable conductive surface material may be in the form of a removable conductive strip wound about the exterior surface of the conductive member. In a preferred embodiment, the conductive member and the removable conductive surface material form a single, discreet contact.

In accordance with a still further aspect of the present invention, an apparatus for plating a noble metal on a microelectronic workpiece is disclosed that comprises a reactor chamber that contains an electroplating solution having ions or complexes of the noble metal or noble metal alloy that is to be plated onto the workpiece. The apparatus also includes a workpiece support including a contact assembly for providing electroplating power to a surface at a side of the workpiece that is to be plated and an anode spaced from the workpiece support within the reaction chamber and contacting the electroplating solution. A chemical delivery system is employed for supplying the electroplating solution to the reactor chamber and recirculating electroplating solution removed from the reactor chamber. To eliminate fouling of the solution,

as is quite prevalent when plating a noble metal, a multi-stage filtration system is utilized. The filtration system is disposed within the chemical delivery system for filtering electroplating solution removed from the reactor chamber before it is re-supplied to the reactor chamber. It includes at least a first filter stage for filtering particles greater than or equal to a first size and a second filter stage disposed downstream of the first filter stage for filtering particles greater than or equal to a second size, the first size being greater in magnitude than the second size.

It may be desirable to use a current thief in any of the foregoing electroplating apparatus. In accordance with a still further aspect of the present invention, a disposable current thief is set forth. The disposable current thief is disposed in the electroplating solution between the anode and the contact assembly and is formed from the conductive portions of a printed circuit board. The disclosed current thief is manufactured from readily available materials using simple manufacturing processes thereby significantly reducing the costs of providing current thieving in noble metal electroplating processes.

A method for electroplating a noble metal onto the surface of a microelectronic workpiece is also set forth. Although the method is generally apparatus independent, any of the foregoing apparatus may be used to implement the method. Generally stated, the method involves bringing the surface of the workpiece that is to be plated into contact with an electroplating solution including ions or complexes of a noble metal or noble metal alloy that is

to be plated on the surface of the workpiece. Electroplating power is applied between the surface of the workpiece and an anode using a low current for a first predetermined period of time. This is subsequently followed at a later time by application of full-scale electroplating power between the surface of the workpiece and the anode for a second predetermined period of time. In many instances, it is preferable, though not necessary, to provide the low current as the initial electroplating power and to have the full-scale electroplating power applied immediately thereafter. At a time subsequent to the end of the second predetermined period of time, electroplating power is removed and the surface of the workpiece is disengaged from the electroplating solution. Suitable parameters for electroplating the noble metal using an acidic electroplating solution as well as an alkaline electroplating solution are also set forth.

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DETAILED DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a cross-sectional view through an electroplating reactor that is constructed in accordance with various teachings of the present invention.

FIGURE 2 illustrates a specific construction of one embodiment of a reactor bowl suitable for use in the assembly illustrated in FIGURE 1.

FIGURE 3 illustrates one embodiment of a reactor head, comprised of a stationary assembly and a rotor assembly that is suitable for use in the assembly illustrated in FIGURE 1.

FIGUREs 4 - 10 illustrate one embodiment of a contact assembly using flexure contacts that is suitable for use in the reactor assembly illustrated in FIGURE 1.

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~~FIGUREs 11 - 12 illustrate two different embodiments of a "Belleville ring" contact structure~~.

FIGUREs 13 - 15 illustrate one embodiment of a contact assembly using a "Belleville ring" contact structure, such as one of those illustrated in FIGURES 11-12, that is suitable for use in the reactor assembly illustrated in FIGURE 1.

FIGURE 16A is a schematic block diagram of a flow system for supplying the plating solution to the reactor bowl.

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~~FIGUREs 16B - 20 illustrate various aspects of one embodiment of a quick-attach~~

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FIGURE 21 is a cross-sectional view of the reactor head illustrating the disposition of the reactor head in a condition in which it may accept a workpiece.

FIGURE 22 is a cross-sectional view of the reactor head illustrating the disposition of the reactor head in a condition in which it is ready to present the workpiece to the reactor bowl.

FIGURE 23 illustrates an exploded view one embodiment of the rotor assembly.

FIGURE 24 illustrates one embodiment of a segmented current thief suitable for noble metal plating.

FIGURE 25 illustrates one embodiment of a finger contact that may also function as a current thief in the plating of noble metals.

FIGURES 26 - 28 are top plan views of integrated processing tools that may incorporate electroless plating reactors and electroplating reactors in combination.

FIGURES 29 – 32 are various views of a further embodiment of a reactor base for providing a flow of electroplating solution to the surface of a workpiece in which the flow assists in increasing the uniformity of the electroplated noble metal layer.

DETAILED DESCRIPTION OF THE INVENTION

BASIC NOBLE METAL ELECTROPLATING REACTOR COMPONENTS

With reference to FIGURES 1 - 3, there is shown a reactor assembly 20 for electroplating a noble metal on the surface of a microelectronic workpiece, such as a semiconductor wafer 25. Generally stated, the reactor assembly 20 is comprised of a reactor head 30 and a corresponding reactor bowl 35. This type of reactor assembly is particularly suited for effecting electroplating of semiconductor wafers or like workpieces, in which an electrically conductive, thin-film seed layer of the wafer is electroplated with a blanket or patterned noble metal layer, such as a layer of platinum.

A specific construction of one embodiment of a reactor bowl 35 suitable for use in the reactor assembly 20 is illustrated in FIGURE 2. The electroplating reactor bowl 35 is that portion of the reactor assembly 20 that contains electroplating solution, and that directs the solution at a high flow rate against a generally downwardly facing surface of an associated workpiece 25 to be plated. To this end, electroplating solution is circulated through the reactor bowl 35. Attendant to solution circulation, the solution flows from the reactor bowl 35, over the weir-like periphery of the bowl, into a lower overflow chamber 40 of the reactor assembly 20. Solution is drawn from the overflow chamber typically for re-circulation through the reactor.

The temperature of the electroplating solution is monitored and maintained by a temperature

sensor and heater, respectively. The sensor and heater are disposed in the circulation path of the electroplating solution. For electroplating noble metals and their alloys, particularly platinum and platinum alloys, these components maintain the temperature of the electroplating solution in a temperature range between 40 °C and 80 °C. Even more preferably, these components maintain the temperature of the electroplating solution at about 65°C 0.5. As will be explained in connection with the preferred electroplating process, the electroplating solution exhibits optimal deposition properties within this latter temperature range.

The reactor bowl 35 includes a riser tube 45, within which an inlet conduit 50 is positioned for introduction of electroplating solution into the interior portion of the reactor bowl 35. The inlet conduit 50 is preferably conductive and makes electrical contact with and supports an electroplating anode 55. Anode 55 is preferably an inert anode, and, in at least one of the preferred methods, a platinized titanium inert anode is used. The electrically-conductive surface of the workpiece functions as a cathode.

Electroplating solution flows at a high flow rate, preferably at a rate of 5 gal/min, from the inlet conduit 50 through openings at the upper portion thereof. From there, the solution flows about the anode 55, and through an optional diffusion plate 65 positioned in operative association with and between the cathode (workpiece) and the anode.

The reactor head 30 of the electroplating reactor 20 is preferably comprised of a stationary

assembly 70 and a rotor assembly 75, diagrammatically illustrated in FIGURE 3. Rotor assembly 75 is configured to receive and carry an associated wafer 25 or like workpiece, position the wafer in a process-side down orientation within reactor bowl 35, and to rotate or spin the workpiece while joining its electrically-conductive surface in the plating circuit of the reactor assembly 20. The reactor head 30 is typically mounted on a lift/rotate apparatus 80, which is configured to rotate the reactor head 30 from an upwardly-facing disposition, in which it receives the wafer to be plated, to a downwardly facing disposition, in which the surface of the wafer to be plated is positioned downwardly in reactor bowl 35, generally in confronting relationship to diffusion plate 65. A robotic arm 418, including an end effector, is typically employed for placing the wafer 25 in position on the rotor assembly 75, and for removing the plated wafer from the rotor assembly.

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It will be recognized that other reactor assembly configurations may be used with the inventive aspects of the disclosed reactor head, the foregoing being merely illustrative. Another reactor assembly suitable for use in the foregoing configuration is illustrated in U.S.S.N. _______, entitled "Workpiece Processor Having Improved Processing Chamber", filed July 12, 1999 (Attorney Docket No. SEM4492P0831US) and further reactor assembly illustrated in U.S.S.N. 60/120,955, filed April 13, 1999, both of which are incorporated herein by reference.

ELECTROPLATING SOLUTIONS

The plating bath that is used in the reactor 35 depends upon the particular noble metal or noble metal alloy that is to be plated. Examples of suitable plating solutions for plating noble metals include: 1) for gold - cyanide-based or sulfite-based baths (such as Enthone-OMI Neutronex 309); 2) for ruthenium - a sulfamate, nitrosyl sulfamate or nitroso-based bath (such as Technic's Ruthenium U, Englehard's Ru-7 and Ru-8, and LeaRonal's Decronal White 44 and Decronal Black 44); and 4) for platinum - a potassium hydroxide-based based, ammonia-sulfamate-based, or sulfate-based bath (such as Englehard's Platinum A bath or Technics Platinum S bath).

The particular solution for each selected metal is partially dependent upon the particular plating process being used. For example, with respect to platinum, a potassium hydroxide-based solution, such as Englehard's Platinum A, is well suited for use in an alkaline plating process, while an ammonia-sulfamate-based solution (such as Technic's Platinum S) is particularly well suited for use in a photoresist template process. Careful control of temperature and pH of the bath is often required for optimal plating results. Such parameters are typically placed under the control of a programmable control system.

Exemplary Process

An exemplary process sequence for plating a noble metal or noble metal alloy, such as platinum or a platinum alloy, onto the surface of a workpiece in a reactor assembly, such as the

reactor assembly illustrated in FIGURES 1-3, includes the following processing steps:

(Optional) Pre-wet/Pre-clean the substrate material using deionized water or acid and/or a surfactant to eliminate the dry plating surface (about 30 seconds) (the pre-wet solution may be heated to the same temperature at which electroplating will occur);

Adjust and/or program (either manually or using the programmable control system) the electroplating system for the appropriate processing parameters, including electroplating solution flow rate, pH, temperature, concentration of metal or alloy to be deposited, current density and waveform of electroplating power applied, and rotation rate of workpiece;

Bring the surface of the workpiece that is to be plated into contact with the noble metal or noble metal alloy electroplating solution;

(Optional) Apply an initial low electroplating current for a first predetermined period of time to initiate electroplating of the workpiece;

Apply full-scale electroplating current for the duration necessary to achieve the desired depth of deposited material;

Halt electrolysis;

Disengage the workpiece from electroplating solution;

Spin the workpiece at a high spin rate (i.e., above about 200 rpm) to remove excess

electroplating solution;

Rinse the workpiece in a spray of deionized water (about 2 min.) and spin dry at a high rotation rate;

(Optional) Subject the workpiece to a backside cleaning process to remove any backside contamination, such as potassium hydroxide contamination

For an alkaline platinum plating process, the preferred processing parameters include a flow rate of about 5 gallons per minute using a plating solution having a temperature of 65°C, a pH in the range of about 11-12, preferably about 11.5, and a platinum concentration in the range of about 10 – 15 g/l, preferably 12.5 g/l. Electroplating power is applied having a current density between about 3 and 9 mA/cm^2 , depending on the seed layer type, with low current initiation using a pulsed waveform having a pattern of 1 ms on, 1 ms off, or DC (again, depending on the seed layer material).

Low current initiation is often desirable. If a seed layer is to thin, lacks sufficient adhesion, or is too highly stressed, cracking and peeling can occur at electroplating contact points and/or structures (e.g., posts, trenches, etc.). This may be due to high localized current densities. A low current initiation step allows for a slow build-up of platinum, or other noble metal, in these areas. When the thickness has increased beyond a predetermined magnitude, the current (and plating rate) can be increased without stress cracking. The predetermined magnitude can be determined

experimentally.

Deposition rates in excess of 320 angstroms/min are typical using the above noted parameters. A process using the same parameters, with the exception of applying a DC waveform, can result in deposition rates that are in excess of 740 angstroms /min. The current density that is used is principally limited by the amount of hydrogen gas that evolves during the electroplating process. Hydrogen gas may then be trapped in the plated film thereby resulting in stress cracking. There is therefore a trade-off that must be made between the deposition rate and the risk of stress cracking.

The alkaline platinum plating process using the above parameters has exhibited high throwing power with respect to submicron features, making it well suited for the formation of 3D plug capacitor electrodes. Such electrodes require a conformal platinum layer that is defect free, and non-porous. A For 3D plug capacitors, plating thickness in an ultra thin layer less than 500 Å is typical.

The foregoing alkaline platinum plating process is generally unsuitable for use in patterned plating in which photoresist is used as the plating mask unless the photoresist has been specifically chosen and treated (e.g., deep ultraviolet bake) for use in an alkaline plating bath. Rather, an acidic plating bath is preferred for such processes. The present inventors have likewise developed an acidic platinum plating process that is suitable for use in processes employing a photoresist mask. The

preferred processing parameters include a flow rate of 5 gallons per minute for a plating solution having a temperature of 65°C, a pH in the range of about 2 – 4, preferably about 3.0, and a platinum concentration in the range of about 2 – 16 g/l, preferably about 4.0 g/l. Electroplating power is applied having a current density in the range of about 20 – 50 mA/cm^2, preferably about 34.5 mA/cm^2 using a pulsed waveform. The waveform may have an on time of about 1 – 10 ms, preferably of 1 ms, and an off time of about 1 – 10 ms, preferably 1 ms off. Deposition rates in excess of 550 angstroms/min are typical using the above noted acidic platinum plating parameters. The acidic platinum plating process is well suited for the formation of patterned capacitors, where a plating thickness of about 2500 angstroms is typical.

As noted above, the plating process is typically applied to a workpiece having a seed layer on top of a barrier layer. Typically the seed layer is applied to the barrier layer using physical vapor deposition. The characteristics of the barrier layer and the seed layer, including the type of material and thickness, can have an impact on stress cracking and plating uniformity. Preferred barrier layer materials include TiN, Ta, TaN, Ti, and TiO2.

Similar plating processes, or ones with only slight modifications, using the particular plating bath required, can be used to plate other noble metals, or noble metal alloys. As will be set forth in further detail below, the foregoing processing steps and sequence may be implemented in a single fabrication tool having a plurality of similar processing stations and a programmable robot that

transfers the workpieces between such stations.

There are a number of enhancements that may be made to the reactor assembly 20 described above that facilitate uniformity of the noble metal deposits over the face of the workpiece. For example, the reactor assembly 20 may use a contact assembly that reduces non-uniformities in the deposits that occur proximate the discrete contacts that are used to provide plating power to the surface at the perimeter of the workpiece, including the alternative use of a continuous or a semi-continuous ring contact. Additionally, other enhancements to the reactor assembly 20 may be added to facilitate routine service and/or configurability of the system.

IMPROVED CONTACT ASSEMBLIES

As noted above, the manner in which the electroplating power is supplied to the wafer at the peripheral edge thereof is very important to the overall film quality of the deposited metal. Some of the more desirable characteristics of a contact assembly used to provide such electroplating power include, for example, the following:

- uniform distribution of electroplating power about the periphery of the wafer to maximize the uniformity of the deposited film;
- consistent contact characteristics to insure wafer-to-wafer uniformity;
- minimal intrusion of the contact assembly on the wafer periphery to maximize the

available area for device production; and

- minimal plating on the barrier layer about the wafer periphery to inhibit peeling and/or flaking.

To meet one or more of the foregoing characteristics, reactor 20 preferably employs a ring contact assembly 85 that provides either a continuous electrical contact or a high number of discrete electrical contacts with the wafer 25. By providing a more continuous contact with the outer peripheral edges of the semiconductor wafer 25, in this case around the outer circumference of the semiconductor wafer, a more uniform current is supplied to the semiconductor wafer 25 that promotes more uniform current densities. The more uniform current densities enhance uniformity in the depth of the deposited material.

Contact assembly 85, in accordance with a preferred embodiment, includes contact members that provide minimal intrusion about the wafer periphery while concurrently providing consistent contact with the seed layer. Contact with the seed layer is enhanced by using a contact member structure that provides a wiping action against the seed layer as the wafer is brought into engagement with the contact assembly. This wiping action assists in removing any oxides at the seed layer surface thereby enhancing the electrical contact between the contact structure and the seed layer. As a result, uniformity of the current densities about the wafer periphery are increased and the resulting film is more uniform. Further, such consistency in the electrical

contact facilitates greater consistency in the electroplating process from wafer-to-wafer thereby increasing wafer-to-wafer uniformity.

Contact assembly 85, as will be set forth in further detail below, also preferably includes one or more structures that provide a barrier, individually or in cooperation with other structures, that separates the contact/contacts, the peripheral edge portions and backside of the semiconductor wafer 25 from the plating solution. This prevents the plating of metal onto the individual contacts and, further, assists in preventing any exposed portions of the barrier layer near the edge of the semiconductor wafer 25 from being exposed to the electroplating environment. As a result, plating of the barrier layer and the appertaining potential for contamination due to flaking of any loosely adhered electroplated material is substantially limited.

RING CONTACT ASSEMBLIES USING FLEXURE CONTACTS

One embodiment of a contact assembly suitable for use in the assembly 20 is shown generally at 85 of FIGURES 4 - 10. The contact assembly 85 forms part of the rotor assembly 75 and provides electrical contact between the semiconductor wafer 25 and a source of electroplating power. In the illustrated embodiment, electrical contact between the semiconductor wafer 25 and the contact assembly 85 occurs at a large plurality of discrete

flexure contacts 90 that are effectively separated from the electroplating environment interior of the reactor bowl 35 when the semiconductor wafer 25 is held and supported by the rotor assembly 75.

The contact assembly 85 may be comprised of several discrete components. With reference to FIGURE 4, when the workpiece that is to be electroplated is a circular semiconductor wafer, the discrete components of the contact assembly 85 join together to form a generally annular component having a bounded central open region 95. It is within this bounded central open region 95 that the surface of the semiconductor wafer that is to be electroplated is exposed. With particular reference to FIGURE 6, contact assembly 85 includes an outer body member 100, an annular wedge 105, a plurality of flexure contacts 90, a contact mount member 110, and an interior wafer guide 115. Preferably, annular wedge 105, flexure contacts 90, and contact mount member 110 are formed from platinized titanium while wafer guide 115 and outer body member 100 are formed from a dielectric material that is compatible with the electroplating environment. Annular wedge 105, flexure contacts 90, mount member 110, and wafer guide 115 join together to form a single assembly that is secured together by outer body member 100.

As shown in FIGURE 6, contact mount member 110 includes a first annular groove 120 disposed about a peripheral portion thereof and a second annular groove 125 disposed radially

inward of the first annular groove 120. The second annular groove 125 opens to a plurality of flexure channels 130 that are equal in number to the number of flexure contacts 90. As can be seen from FIGURE 4, a total of 36 flexure contacts 90 are employed, each being spaced from one another by an angle of about 10 degrees.

Referring again to FIGURE 6, each flexure contact 90 is comprised of an upstanding portion 135, a transverse portion 140, a vertical transition portion 145, and a wafer contact portion 150. Similarly, wedge 105 includes an upstanding portion 155 and a transverse portion 160. Upstanding portion 155 of wedge 105 and upstanding portion 135 of each flexure contact 90 are secured within the first annular groove 120 of the contact mount member 110 at the site of each flexure channel 130. Self-adjustment of the flexure contacts 90 to their proper position within the overall contact assembly 85 is facilitated by first placing each of the individual flexure contacts 90 in its respective flexure channel 130 so that the upstanding portion 135 is disposed within the first annular groove 120 of the contact mount member 110 while the transition portion 145 and contact portion 150 proceed through the respective flexure channel 130. The upstanding portion 155 of wedge member 105 is then urged into the first annular groove 120. To assist in this engagement, the upper end of upstanding portion 155 is tapered. The combined width of upstanding portion 135 of the flexure contact 90 and upstanding portion 155 of wedge 105 are such that these components are firmly secured with contact mount member 110.

Transverse portion 160 of wedge 105 extends along a portion of the length of transverse portion 140 of each flexure 90. In the illustrated embodiment, transverse portion 160 of wedge portion 105 terminates at the edge of the second annular groove 125 of contact mount member 110. As will be more clear from the description of the flexure contact operation below, the length of transverse portion 160 of wedge 105 can be chosen to provide the desired degree of stiffness of the flexure contacts 90.

Wafer guide 115 is in the form of an annular ring having a plurality of slots 165 through which contact portions 150 of flexures 90 extend. An annular extension 170 proceeds from the exterior wall of wafer guide 115 and engages a corresponding annular groove 175 disposed in the interior wall of contact mount member 110 to thereby secure the wafer guide 115 with the contact mount member 110. As illustrated, the wafer guide member 115 has an interior diameter that decreases from the upper portion thereof to the lower portion thereof proximate contact portions 150. A wafer inserted into contact assembly 85 is thus guided into position with contact portions 150 by a tapered guide wall formed at the interior of wafer guide 115. Preferably, the portion 180 of wafer guide 115 that extends below annular extension 170 is formed as a thin, compliant wall that resiliently deforms to accommodate wafers having different diameters within the tolerance range of a given wafer size. Further, such resilient deformation accommodates a range of wafer insertion tolerances occurring in the components used to bring the wafer into

engagement with the contact portions 150 of the flexures 90.

Referring to FIGURE 6, outer body member 100 includes an upstanding portion 185, a transverse portion 190, a vertical transition portion 195 and a further transverse portion 200 that terminates in an upturned lip 205. Upstanding portion 185 includes an annular extension 210 that extends radially inward to engage a corresponding annular notch 215 disposed in an exterior wall of contact mount member 110. A V-shaped notch 220 is formed at a lower portion of the upstanding portion 185 and circumvents the outer periphery thereof. The V-shaped notch 220 allows upstanding portion 185 to resiliently deform during assembly. To this end, upstanding portion 185 resiliently deforms as annular extension 210 slides about the exterior of contact mount member 110 to engage annular notch 215. Once so engaged, contact mount member 110 is clamped between annular extension 210 and the interior wall of transverse portion 190 of outer body member 100.

Further transverse portion 200 extends beyond the length of contact portions 150 of the flexure contacts 90 and is dimensioned to resiliently deform as a wafer, such as at 25, is driven against them. V-shaped notch 220 may be dimensioned and positioned to assist in the resilient deformation of transverse portion 200. With the wafer 25 in proper engagement with the contact portions 150, upturned lip 205 engages wafer 25 and assists in providing a barrier between the electroplating solution and the outer peripheral edge and backside of wafer 25, including the

flexure contacts 90.

As illustrated in FIGURE 6, flexure contacts 90 resiliently deform as the wafer 25 is driven against them. Preferably, contact portions 150 are initially angled upward in the illustrated manner. Thus, as the wafer 25 is urged against contact portions 150, flexures 90 resiliently deform so that contact portions 150 effectively wipe against surface 230 of wafer 25. In the illustrated embodiment, contact portions 150 effectively wipe against surface 230 of wafer 25 a horizontal distance designated at 235. This wiping action assists in removing and/or penetrating any oxides from surface 230 of wafer 25 thereby providing more effective electrical contact between flexure contacts 90 and the seed layer at surface 230 of wafer 25.

With reference to FIGUREs 7 and 8, contact mount member 110 is provided with one or more ports 240 that may be connected to a source of purging gas, such as a source of nitrogen. As shown in FIGURE 8, purge ports 240 open to second annular groove 125 which, in turn, operates as a manifold to distribute the purging gas to all of the flexure channels 130 as shown in FIGURE 6. The purging gas then proceeds through each of the flexure channels 130 and slots 165 to substantially surround the entire contact portions 150 of flexures 90. In addition to purging the area surrounding contact portions 150, the purge gas cooperates with the upturned lip 205 of outer body member 100 to effect a barrier to the electroplating solution. Further circulation of the purge gas is facilitated by an annular channel 250 formed between a portion of

the exterior wall of wafer guide 115 and a portion of the interior wall of contact mount member 110.

As shown in FIGUREs 4, 5 and 10, contact mount member 110 is provided with one or more threaded apertures 255 that are dimensioned to accommodate a corresponding connection plug 260. With reference to FIGUREs 5 and 10, connection plugs 260 provide electroplating power to the contact assembly 85 and, preferably, are each formed from platinized titanium. In a preferred form of plugs 260, each plug 260 includes a body 265 having a centrally disposed bore hole 270. A first flange 275 is disposed at an upper portion of body 265 and a second flange 280 is disposed at a lower portion of body 265. A threaded extension 285 proceeds downward from a central portion of flange 280 and secures with threaded bore hole 270. The lower surface of flange 280 directly abuts an upper surface of contact mount member 110 to increase the integrity of the electrical connection therebetween.

Although flexure contacts 90 are formed as discrete components, they may be joined with one another as an integral assembly. To this end, for example, the upstanding portions 135 of the flexure contacts 90 may be joined to one another by a web of material, such as platinized titanium, that is either formed as a separate piece or is otherwise formed with the flexures from a single piece of material. The web of material may be formed between all of the flexure contacts or between select groups of flexure contacts. For example, a first web of material may be used to

join half of the flexure contacts (e.g., 18 flexure contacts in the illustrated embodiment) while a second web of material is used to join a second half of the flexure contacts (e.g., the remaining 18 flexure contacts in the illustrated embodiment). Different groupings are also possible.

BELLEVILLE RING CONTACT ASSEMBLIES

Alternative contact assemblies are illustrated in FIGUREs 11 – 15. In each of these contact assemblies, the contact members are integrated with a corresponding common ring and, when mounted in their corresponding assemblies, are biased upward in the direction in which the wafer or other substrate is received upon the contact members. A top view of one embodiment of such a structure is illustrated in FIGURE 11A while a perspective view thereof is illustrated in FIGURE 11B. As illustrated, a ring contact, shown generally at 610, is comprised of a common ring portion 630 that joins a plurality of contact members 655. The common ring portion 630 and the contact members 655, when mounted in the corresponding assemblies, are similar in appearance to half of a conventional Belleville spring. For this reason, the ring contact 610 will be hereinafter referred to as a "Bellville ring contact" and the overall contact assembly into which it is placed will be referred to as a "Bellville ring contact assembly".

The embodiment of Belleville ring contact 610 illustrated in FIGUREs 11A and 11B includes 72 contact members 655 and is preferably in formed from platinized titanium. The

contact members 655 may be formed by cutting arcuate sections 657 into the interior diameter of a platinized titanium ring. A predetermined number of the contact members 658 have a greater length than the remaining contact members 655 to, for example, accommodate certain flat-sided wafers.

A further embodiment of a Belleville ring contact 610 is illustrated in FIGURE 12. As above, this embodiment is preferably formed from platinized titanium. Unlike the embodiment of FIGUREs 11A and 11B in which all of the contact members 655 extend radially inward toward the center of the structure, this embodiment includes contact members 659 that are disposed at an angle. This embodiment constitutes a single-piece design that is easy to manufacture and that provides a more compliant contact than does the embodiment of FIGUREs 11A and 11B with the same footprint. This contact embodiment can be fixtured into the "Belleville" form in the contact assembly and does not require permanent forming. If the Belleville ring contact 610 of this embodiment is fixtured in place, a complete circumferential structure is not required. Rather the contact may be formed and installed in segments thereby enabling independent control/sensing of the electrical properties of the segments.

A first embodiment of a Bellville ring contact assembly is illustrated generally at 600 in in FIGURES 13-15. As illustrated, the contact assembly 600 comprises a conductive contact mount member 605, a Bellville ring contact 610, a dielectric wafer guide ring 615, and an outer

body member 625. The outer, common portion 630 of the Bellville ring contact 610 includes a first side that is engaged within a notch 675 of the conductive base ring 605. In many respects, the Belleville ring contact assembly of this embodiment is similar in construction with the flexure contact assembly 85 described above. For that reason, the functionality of many of the structures of the contact assembly 600 will be apparent and will not be repeated here.

Preferably, the wafer guide ring 615 is formed from a dielectric material while contact mount member 605 is formed from a single, integral piece of conductive material or from a dielectric or other material that is coated with a conductive material at its exterior. Even more preferably, the conductive ring 605 and Bellville ring contact 610 are formed from platinized titanium or are otherwise coated with a layer of platinum.

The wafer guide ring 615 is dimensioned to fit within the interior diameter of the contact mount member 605. Wafer guide ring 615 has substantially the same structure as wafer guides 115 and 115b described above in connection with contact assemblies 85 and 85b, respectively. Preferably, the wafer guide ring 615 includes an annular extension 645 about its periphery that engages a corresponding annular slot 650 of the conductive base ring 605 to allow the wafer guide ring 615 and the contact mount member 605 to snap together.

The outer body member 625 includes an upstanding portion 627, a transverse portion 629, a vertical transition portion 632 and a further transverse portion 725 that extends radially

and terminates at an upturned lip 730. Upturned lip 730 assists in forming a barrier to the electroplating environment when it engages the surface of the side of workpiece 25 that is being processed. In the illustrated embodiment, the engagement between the lip 730 and the surface of workpiece 25 is the only mechanical seal that is formed to protect the Bellville ring contact 610.

The area proximate the contacts 655 of the Belleville ring contact 610 is preferably purged with an inert fluid, such as nitrogen gas, which cooperates with lip 730 to effect a barrier between the Bellville ring contact 610, peripheral portions and the backside of wafer 25, and the electroplating environment. As particularly shown set forth in FIGUREs 19 and 20, the outer body member 625 and contact mount member 605 are spaced from one another to form an annular cavity 765. The annular cavity 765 is provided with an inert fluid, such as nitrogen, through one or more purge ports 770 disposed through the contact mount member 605. The purged ports 770 open to the annular cavity 765, which functions as a manifold to distribute to the inert gas about the periphery of the contact assembly. A given number of slots, such as at 780, corresponding to the number of contact members 655 are provided and form passages that route the inert fluid from the annular cavity 765 to the area proximate contact members 655.

FIGUREs 14 and 15 also illustrate the flow of a purging fluid in this embodiment of Bellville ring contact assembly. As illustrated by arrows, the purge gas enters purge port 770 and is distributed about the circumference of the assembly 600 within annular cavity 765. The

purged gas then flows through slots 780 and below the lower end of contact mount member 605 to the area proximate Bellville contact 610. At this point, the gas flows to substantially surround the contact members 655 and, further, may proceed above the periphery of the wafer to the backside thereof. The purging gas may also proceed through an annular channel 712 defined by the contact mount member 605 and the interior of the compliant wall formed at the lower portion of wafer guide ring 615. Additionally, the gas flow about contact members 655 cooperates with upturned lip 730 effect a barrier at lip 730 that prevents electroplating solution from proceeding therethrough.

When a wafer or other workpiece 25 is urged into engagement with the contact assembly 600, the workpiece 25 first makes contact with the contact members 655. As the workpiece is urged further into position, the contact members 655 deflect and effectively wipe the surface of workpiece 25 until the workpiece 25 is pressed against the upturned lip 730. This mechanical engagement, along with the flow of purging gas, effectively isolates the outer periphery and backside of the workpiece 25 as well as the Bellville ring contact 610 from contact with the plating solution.

Other similar contact assembly designs that have a large number of contacts and that isolate the contacts from the electroplating environment are likewise suitable for use in the disclosed reactor assembly. Such additional contact assembly designs are set forth, for example,

in PCT Application _, filed July 9, 1999 (Attorney Docket No. SEM4492P0571PC), which is hereby incorporated by reference.

PLATING BATH FILTRATION SYSTEM

While platinum will plate over the barrier layer the platinum will not readily adhere to materials preferably used for the barrier layer (i.e. Ti, Ta, TaN, TiO_2, TiAlN). As a result, the plated platinum tends to flake off of the barrier layer and pollute the electroplating solution. By limiting the formation of plated platinum on the barrier layer, a significant source of platinum flakes is substantially reduced.

Prior to supplying the recirculated solution to the plating module, the solution is filtered so as to limit pollutants in the solution, like platinum flakes. The filtered particles will eventually clog the filter and the filter will need to be replaced. By limiting the flaking of plated material the operational life of the filter is extended. So as to further extend the operational life of the filter, and/or in instances where platinum is allowed to form on the barrier layer, the use of a cascaded filter 201 has been determined to be beneficial. As illustrated in FIGURE 16A, preferably a three-stage filter is used between the electroplating reactor 20 and the plating solution source tank 22. In the illustrated embodiment, the first stage 202 provides filtration of particles of a first predetermined size or larger, the second stage 203 provides filtration of particles of a second predetermined size or larger, and the

third stage 204 provides filtration of particles of a third predetermined size or larger. In the preferred embodiment, the first stage 202 provides filtration of particles 4.5μm or larger, the second stage 203 provides filtration of particles 1.0μm or larger, and the third stage 204 provides filtration of particles 0.1μm or larger.

ROTOR CONTACT CONNECTION ASSEMBLY

In many instances, it may be desirable to have a given reactor assembly 20 function to execute a wide range of noble metal electroplating recipes. Execution of a wide range of electroplating recipes may be difficult, however, if the process designer is limited to using a single contact assembly construction. Further, the plating contacts used in a given contact assembly construction must be frequently inspected and, sometimes, replaced. This is often difficult to do in existing electroplating reactor tools, frequently involving numerous operations to remove and/or inspect the contact assembly. This problem may be addressed by providing a mechanism by which the contact assembly 85 is readily attached and detached from the other components of the rotor assembly 75. Further, a given contact assembly type can be replaced with the same contact assembly type without re-calibration or readjustment of the system.

To be viable for operation in a manufacturing environment, such a mechanism must accomplish several functions including:

1. Provide secure, fail-safe mechanical attachment of the contact assembly to other portions of the rotor assembly;
2. Provide electrical interconnection between the contacts of the contact assembly and a source of electroplating power;
3. Provide a seal at the electrical interconnect interface to protect against the processing environment (e.g., wet chemical environment);
4. Provide a sealed path for the purge gas that is provided to the contact assembly; and
5. Minimize use of tools or fasteners which can be lost, misplaced, or used in a manner that damages the electroplating equipment.

FIGURES 16B and 17 illustrate one embodiment of a quick-attach mechanism that meets the foregoing requirements. For simplicity, only those portions of the rotor assembly 75 necessary to understanding the various aspects of the quick-attach mechanism are illustrated in these figures.

As illustrated, the rotor assembly 75 may be comprised of a rotor base member 1205 and a removable contact assembly 1210. Preferably, the removable contact assembly 1210 is constructed in the manner set forth above in connection with contact assembly 85. The illustrated embodiment, however, employs a continuous ring contact. It will be recognized that both contact assembly constructions are suitable for use with the quick-attachment mechanism

set forth herein.

The rotor base member 1205 is preferably annular in shape to match the shape of the semiconductor wafer 25. A pair of latching mechanisms 1215 are disposed at opposite sides of the rotor base member 205. Each of the latching mechanisms 1215 includes an aperture 1220 disposed through an upper portion thereof that is dimensioned to receive a corresponding electrically conductive shaft 1225 that extends downward from the removable contact assembly 1210.

The removable contact assembly 1210 is shown in a detached state in FIGURE 16B. To secure the removable contact assembly 1210 to the rotor base member 1205, an operator aligns the electrically conductive shafts 1225 with the corresponding apertures 1220 of the latching mechanisms 1215. With the shafts 1225 aligned in this manner, the operator urges the removable contact assembly 1210 toward the rotor base member 1205 so that the shafts 1225 engage the corresponding apertures 1220. Once the removable contact assembly 1210 is placed on the rotor base member 1205, latch arms 1230 are pivoted about a latch arm axis 1235 so that latch arm channels 1240 of the latch arms 1230 engage the shaft portions 1245 of the conductive shafts 1235 while concurrently applying a downward pressure against flange portions 1247. This downward pressure secures the removable contact assembly 1210 with the rotor base assembly 1205. Additionally, as will be explained in further detail below, this engagement results in the

creation of an electrically conductive path between electrically conductive portions of the rotor base assembly 1205 and the electroplating contacts of the contact assembly 1210. It is through this path that the electroplating contacts of the contact assembly 1210 are connected to receive power from a plating power supply.

FIGURES 18A and 18B illustrate further details of the latching mechanisms 1215 and the electrically conductive shafts 1225. As illustrated, each latching mechanism 1215 is comprised of a latch body 1250 having aperture 1220, a latch arm 1230 disposed for pivotal movement about a latch arm pivot post 1255, and a safety latch 1260 secured for relatively minor pivotal movement about a safety latch pivot post 1265. The latch body 1250 may also have a purge port 270 disposed therein to conduct a flow of purging fluid to corresponding apertures of the removable contact assembly 210. An O-ring 275 is disposed at the bottom of the flange portions of the conductive shafts 1225

FIGURES 19A – 19C are cross-sectional views illustrating operation of the latching mechanisms 1215. As illustrated, latch arm channels 1240 are dimensioned to engage the shaft portions 1245 of the conductive shafts 1225. As the latch arm 1230 is rotated to engage the shaft portions 1245, a nose portion 1280 of the latch arm 1230 cams against the surface 1285 of safety latch 1260 until it mates with channel 1290. With the nose portion 1280 and corresponding channel 1290 in a mating relationship, latch arm 1230 is secured against inadvertent pivotal

movement that would otherwise release removable contact assembly 1210 from secure engagement with the rotor base member 1205.

FIGURES 20A – 20D are cross-sectional views of the rotor base member 1205 and removable contact assembly 1210 in an engaged state. As can be seen in these cross-sectional views, the electrically conductive shafts 1225 include a centrally disposed bore 1295 that receives a corresponding electrically conductive quick-connect pin 1300. It is through this engagement that an electrically conductive path is established between the rotor base member 1205 and the removable contact assembly 1210.

As also apparent from these cross-sectional views, the lower, interior portion of each latch arm 1230 includes a corresponding channel 1305 that is shaped to engage the flange portions 1247 of the shafts 1225. Edge portions of channel 1305 cam against corresponding surfaces of the flange portions 1247 to drive the shafts 1225 against surface 1310 which, in turn, effects a seal with O-ring 1275.

ROTOR CONTACT DRIVE

As illustrated in FIGURES 21, 22 and 23, the rotor assembly 75 includes an actuation arrangement whereby the wafer or other workpiece 25 is received in the rotor assembly by movement in a first direction, and is thereafter urged into electrical contact with the contact

assembly by movement of a backing member 310 toward the contact assembly, in a direction perpendicular to the first direction.

As illustrated, the stationary assembly 70 of the reactor head 30 includes a motor assembly 1315 that cooperates with shaft 1320 of rotor assembly 75. Rotor assembly 75 includes a generally annular housing assembly, including rotor base member 1205 and an inner housing 1320. As described above, the contact assembly is secured to rotor base member 1205. By this arrangement, the housing assembly and the contact assembly 1210 together define an opening 1325 through which the workpiece 25 is transversely movable, in a first direction, for positioning the workpiece in the rotor assembly 75. The rotor base member 1205 preferably defines a clearance opening for the robotic arm as well as a plurality of workpiece supports 3130 upon which the workpiece is positioned by the robotic arm after the workpiece is moved transversely into the rotor assembly by movement through opening 1325. The supports 1330 thus support the workpiece 25 between the contact assembly 1210 and the backing member 1310 before the backing member engages the workpiece and urges it against the contact ring.

Reciprocal movement of the backing member 1310 relative to the contact assembly 1210 is effected by at least one spring which biases the backing member toward the contact assembly, and at least one actuator for moving the backing member in opposition to the spring. In the illustrated embodiment, the actuation arrangement includes an actuation ring 1335 which is

operatively connected with the backing member 1310, and which is biased by a plurality of springs, and moved in opposition to the springs by a plurality of actuators.

With particular reference to FIGURE 21, actuation ring 1335 is operatively connected to the backing member 1310 by a plurality (three) of shafts 1340. The actuation ring, in turn, is biased toward the housing assembly by three compression coil springs 1345 which are each held captive between the actuation ring and a respective retainer cap 350. By this arrangement, the action of the biasing springs 1345 urges the actuation ring 1335 in a direction toward the housing, with the action of the biasing springs thus acting through shafts 1340 to urge the backing member 1335 in a direction toward the contact assembly 1210. The drive shaft 1360 is operatively connected to inner housing 1320 for effecting rotation of workpiece 25, as it is held between contact assembly 210 and backing member 310, during plating prcv ocessing. The drive shaft 360, in turn, is driven by motor 315 that is disposed in the stationary portion of the reactor head 30.

Rotor assembly 75 is preferably detachable from the stationary portion of the reactor head 30 to facilitate maintenance and the like. Thus, drive shaft 1360 is detachably coupled with the motor 1315. In accordance with the preferred embodiment, the arrangement for actuating the backing member 1310 also includes a detachable coupling, whereby actuation ring 1335 can be

coupled and uncoupled from associated actuators which act in opposition to biasing springs 1345.

Actuation ring 1335 includes an inner, interrupted coupling flange 1365. Actuation of the actuation ring 1335 is effected by an actuation coupling 1370 of the stationary assembly 70, which can be selectively coupled and uncoupled from the actuation ring 1335. The actuation coupling 1370 includes a pair of flange portions 1375 which can be interengaged with coupling flange 1365 of the actuation ring 1335 by limited relative rotation therebetween. By this arrangement, the actuation ring 1335 of the rotor assembly 75 can be coupled to, and uncoupled from, the actuation coupling 1370 of the stationary assembly 70 of the reactor head 30.

Actuation coupling 370 is movable in a direction in opposition to the biasing springs 1345 by a plurality of pneumatic actuators 1380 mounted on a frame of the stationary assembly 70. Each actuator 1380 is operatively connected with the actuation coupling 1370 by a respective drive member 1385, each of which extends generally through the frame of the stationary assembly 70.

There is a need to isolate the foregoing mechanical components from other portions of the reactor assembly 20. A failure to do so will result in contamination of the processing environment (here, a wet chemical electroplating environment). Additionally, depending on the

particular process implemented in the reactor 20, the foregoing components can be adversely affected by the processing environment.

To effect such isolation, a bellows assembly 1390 is disposed to surround the foregoing components. The bellows assembly 1390 comprises a bellows member 1395, preferably made from Teflon, having a first end thereof secured at 1400 and a second end thereof secured at 1405. Such securement is preferably implemented using the illustrated liquid-tight, tongue-and-groove sealing arrangement. The convolutes 1410 of the bellows member 1395 flex during actuation of the backing plate 1310.

WAFER LOADING/PROCESSING OPERATIONS

Operation of the reactor head 30 will be appreciated from the above description. Loading of workpiece 25 into the rotor assembly 75 is effected with the rotor assembly in a generally upwardly facing orientation, such as illustrated in FIGURE 3. Workpiece 25 is moved transversely through the opening 325 defined by the rotor assembly 75 to a position wherein the workpiece is positioned in spaced relationship generally above supports 1330. A robotic arm 418 is then lowered (with clearance opening 325 accommodating such movement), whereby the workpiece is positioned upon the supports 1330. The robotic arm 418 can then be withdrawn from within the rotor assembly 75.

The workpiece 25 is now moved perpendicularly to the first direction in which it was moved into the rotor assembly. Such movement is effected by movement of backing member 1310 generally toward contact assembly 1210. It is presently preferred that pneumatic actuators 1380 act in opposition to biasing springs 1345 which are operatively connected by actuation ring 1335 and shafts 1340 to the backing member 1310. Thus, actuators 1380 are operated to permit springs 1345 to bias and urge actuation ring 1335 and, thus, backing member 1310, toward contact 210. FIGURE 22 illustrates the disposition of the reactor head 30 in a condition in which it may accept a workpiece, while FIGURE 21 illustrates the disposition of the reactor head in a condition in which it is ready to present the workpiece to the reactor bowl 35.

In the preferred form, the connection between actuation ring 1335 and backing member 1310 by shafts 1340 permits some "float". That is, the actuation ring and backing member are not rigidly joined to each other. This preferred arrangement accommodates the common tendency of the pneumatic actuators 1380 to move at slightly different speeds, thus assuring that the workpiece is urged into substantial uniform contact with the electroplating contacts of the contact assembly 1210 while avoiding excessive stressing of the workpiece, or binding of the actuation mechanism.

With the workpiece 25 firmly held between the backing member 1310 and the contact assembly 1210, lift and rotate apparatus 80 rotates the reactor head 30 and lowers the reactor

head into a cooperative relationship with reactor bowl 35 so that the surface of the workpiece is placed in contact with the surface of the plating solution (i.e., the meniscus of the plating solution) within the reactor vessel. FIGURE 1 illustrates the apparatus in this condition. If a contact assembly such as contact assembly 85 is used in the reactor 20, the contact assembly 85 seals the entire peripheral region of the workpiece. Depending on the particular electroplating process implemented, it may be useful to insure that any gas which accumulates on the surface of the workpiece is permitted to vent and escape. Accordingly, the surface of the workpiece may be disposed at an acute angle, such as on the order of two degrees from horizontal, with respect to the surface of the solution in the reactor vessel. This facilitates venting of gas from the surface of the workpiece during the plating process as the workpiece, and associated backing and contact members, are rotated during processing. Circulation of plating solution within the reactor bowl 35, as electrical current is passed through the workpiece and the plating solution, effects the desired electroplating of the noble metal or noble metal alloy on the surface of the workpiece.

A number of features of the present reactor facilitate efficient and cost-effective electroplating of a noble metal or noble metal alloy on workpieces such as semiconductor wafers. By use of a contact assembly having substantially continuous contact in the form of a large

number of sealed, compliant discrete contact regions, a high number of plating contacts are provided while minimizing the required number of components. The actuation of the backing member 1310 is desirably effected by a simple linear motion, thus facilitating precise positioning of the workpiece, and uniformity of contact with the contact ring. The isolation of the moving components using a bellows seal arrangement further increases the integrity of the electroplating process.

Maintenance and configuration changes are easily facilitated through the use of the detachable contact assembly 1210. Further, maintenance is also facilitated by the detachable configuration of the rotor assembly 75 from the stationary assembly 70 of the reactor head. The contact assembly provides excellent distribution of electroplating power to the surface of the workpiece, while the preferred provision of the peripheral isolation region protects the contacts from the plating environment (e.g., contact with the plating solution), thereby desirably preventing build-up of noble metal onto the electrical contacts. The perimeter seal also desirably prevents plating onto the peripheral portion of the workpiece.

CURRENT THIEVING IN NOBLE METAL PLATING REACTORS

FIGURE 24 illustrates an embodiment of a current thief that may be used in the plating of noble metals, such as platinum, to enhance the uniformity of the plated film. The embodiment of the

current thief illustrated here may be exposed to the electroplating solution and may be used in conjunction with one or more of the contact assemblies described above or with a plurality of discrete figure contacts such as those described below. Current thieving can be particularly useful where a large number of discrete electrical contacts is not practical. Beneficial features of current thieving are discussed in connection with U.S. Patent Application Serial No. 08/933,450, similarly assigned to Semitool, Inc., the disclosure of which is incorporated herein by reference.

However, in an electroplating environment providing for the deposition of noble metals, certain difficulties associated with the use of current thieves are experienced. One such difficulty is that certain noble metals, like platinum, once plated cannot be readily deplated. The present inventors have addressed this problem and have developed a segmented current thief 415, illustrated in FIGURE 24, that is suitable for use in the plating of noble metals, such as platinum. The segmented current thief 415 provides for multiple pads 420 located about the periphery of the semiconductor wafer 25. Each of the pads 420 can be individually provided with a controlled amount of electroplating power to promote uniform current densities and/or uniform deposition of plated material.

In operation, current thief 415 is a contact with the noble metal plating solution. Plating material will therefore plate the pads 420. As a result, the current thief 415 has a limited useful life before the plating material accumulates to a degree in which it begins to interfere with the optimal

plating process parameters. Accordingly, the current thief 415 is designed to be readily manufactured from inexpensive materials and, as such, is disposable. To this end, current thief 415 is comprised of a printed circuit board with the individual pads separately formed on the printed circuit substrate. Such a current thief 415 could be produced relatively inexpensively, and changed as necessary as part of the regular maintenance. The lower costs of the current thief would help mitigate the expense of more frequent replacement.

In instances where discrete finger contacts are used, current thieving may be provided by a portion of the discrete finger contact. FIGURE 25 shows an example of a discrete finger contact 425. Portions 430 of the finger 425 may have exposed metal for performing a current thieving function.

Because the finger contact 425 often may not be readily replaced with an inexpensive alternative, the finger contacts 425 includes multiple separate conductive wrap layers 435, only one of which will be exposed at any given time. After sufficient build up of deposited material has accumulated one of the conductive wrap layers 435 may be individually removed, exposing a fresh wrap layer underneath. As the individual wrap layers 435 are removed, the accumulation of deposited material is removed with it. In this way the useful life of the finger contact 425 is recycled or renewed.

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INTEGRATED NOBLE METAL PLATING TOOL

Sub 94

FIGURES 26 through 28 are top plan views of integrated processing tools, shown generally at 1450, 1455, and 1500 that may be used to deposit a noble metal on the surface of a microelectronic workpiece, such as a semiconductor wafer. Processing tools 1450 and 1455 are each based on tool platforms developed by Semitool, Inc., of Kalispell, Montana. The processing tool platform of the tool 1450 is sold under the trademark LT-210™, the processing tool platform of the tool 1455 is sold under the trademark LT-210C™, and the processing tool 1500 is sold under the trademark EQUINOX™ . The principal difference between the tools 1450, 1455 is in the footprints required for each. The platform on which tool 1455 is based has a smaller footprint than the platform on which tool 1455 is based. Additionally, the platform on which tool 1450 is based is modularized and may be readily expanded. Each of the processing tools 1450, 1455, and 1500 are computer programmable to implement user entered processing recipes.

Each of the processing tools 1450, 1455, and 1500 include an input/output section 1460, a processing section 1465, and one or more robots 1470. The robots 1470 for the tools 1450, 1455 move along a linear track. The robot 1470 for the tool 1500 is centrally mounted and rotates to access the input/output section 1460 and the processing section 1465. Each input/output section 1460 is adapted to hold a plurality of workpieces, such as semiconductor wafers, in one or more workpiece cassettes. Processing section 1465 includes a plurality of processing stations 1475 that

are used to perform one or more fabrication processes on the semiconductor wafers. The robots 1470 are used to transfer individual wafers from the workpiece cassettes at the input/output section 1460 to the processing stations 1475, as well as between the processing stations 1475.

One or more of the processing stations 1475 are configured as electroplating assemblies, such as the electroplating assembly described above, for electroplating a noble metal, such as platinum, onto the semiconductor wafers. For example, each of the processing tools 1450 and 1455 may include eight noble metal plating reactors and a single pre-wet/rinse station. The pre-wet/rinse station is preferably one of the type available from Semitool, Inc. Preferably, one of the stations may be configured to execute a pre-wet/rinse process, and one of the stations may be configured as a spin rinser/dryer (SRD). Further, one or more of the processing chambers can be configured as an annealing station that can be used to anneal the noble metal layer. It will now be recognized that a wide variation of processing station configurations may be used in each of the individual processing tools 1450, 1455 and 1500 to execute pre-noble metal electroplating and post-noble metal electroplating processes. As such, the foregoing configurations are merely illustrative of the variations that may be used.

ALTERNATIVE PROCESSING CONTAINER

FIGURE 29 illustrates the basic construction of an alternative processing container 35 and the corresponding flow velocity contour pattern resulting from the processing container construction. As illustrated, the processing container 35 generally comprises a main fluid flow chamber 2505, an antechamber 2510, a fluid inlet 2515, a plenum 2520, a flow guide 2525 separating the plenum 2520 from the antechamber 2510, and a nozzle/slot assembly 2530 separating the plenum 2520 from the main chamber 2505. These components cooperate to provide a flow (here, of the electroplating solution) at the wafer 25 with a substantially radially independent normal component. In the illustrated embodiment, the impinging flow is centered about central axis 2535 and possesses a nearly uniform component normal to the surface of the wafer 25. This results in a substantially uniform mass flux to the wafer surface that, in turn, enables substantially uniform processing thereof.

Electroplating solution is provided through inlet 2515 disposed at the bottom of the container 35. The fluid from the inlet 2515 is directed therefrom at a relatively high velocity through antechamber 2510. In the illustrated embodiment, antechamber 2510 includes an accelerated region 2540 through which the electroplating solution flows radially from the fluid inlet 2515 toward fluid flow region 2545 of antechamber 2510. Fluid flow region 2545 has a generally inverted U-shaped cross-section that is substantially wider at its outlet region proximate flow guide 2525 than at its inlet region proximate region 2540. This variation in the

cross-section assists in removing any gas bubbles from the electroplating solution before the electroplating solution is allowed to enter the main chamber 2505. Gas bubbles that would otherwise enter the main chamber 2505 are allowed to exit the processing container 35 through a gas outlet (not illustrated in FIGURE 29, but illustrated in the embodiment shown in FIGURES 30-32) disposed at an upper portion of the antechamber 2510.

Electroplating solution within antechamber 2510 is ultimately supplied to main chamber 2505. To this end, the electroplating solution is first directed to flow from a relatively high-pressure region 2550 of the antechamber 2510 to the comparatively lower-pressure plenum 2520 through flow guide 2525. Nozzle assembly 2530 includes a plurality of nozzles or slots 2555 that are disposed at a slight angle with respect to horizontal. Electroplating solution exits plenum 2520 through nozzles 2555 with fluid velocity components in the horizontal, vertical and radial directions.

Main chamber 2505 is defined at its upper region by a contoured sidewall 2560 and a slanted sidewall 2565. The contoured sidewall 2560 assists in preventing fluid flow separation as the electroplating solution exits nozzles 2555 (particularly the uppermost nozzle(s)) and turns upward toward the surface of wafer 25. Beyond breakpoint 2570, fluid flow separation will not substantially affect the uniformity of the normal flow. As such, sidewall 2565 can generally have any shape, including a continuation of the shape of contoured sidewall 2560. In the specific

embodiment disclosed here, sidewall 2565 is slanted and, as will be explained in further detail below, is used to support one or more anodes.

Electroplating solution exits from main chamber 2505 through a generally annular outlet 2570. Fluid exiting outlet 2570 may be provided to a further exterior chamber for disposal or may be replenished for re-circulation through the electroplating solution supply system.

In those instances in which the processing container 35 forms part of an electroplating reactor, the processing container 35 is provided with one or more anodes. In the illustrated embodiment, a principal anode 2580 is disposed in the lower portion of the main chamber 2505. If the peripheral edges of the surface of the wafer 25 extend radially beyond the extent of contoured sidewall 2560, then the peripheral edges are electrically shielded from principal anode 2580 and reduced plating will take place in those regions. However, if plating is desired in the peripheral regions, one or more further anodes may be employed proximate the peripheral regions. Here, a plurality of annular anodes 2585 are disposed in a generally concentric manner on slanted sidewall 2565 to provide a flow of electroplating current to the peripheral regions. An alternative embodiment would include a single anode or multiple anodes with no shielding from the contoured walls to the edge of the wafer.

The anodes 2580, 2585 may be provided with electroplating power in a variety of manners. For example, the same or different levels of electroplating power may be multiplexed

to the anodes 2580, 2585. Alternatively, all of the anodes 2580, 2585 may be connected to receive the same level of electroplating power from the same power source. Still further, each of the anodes 2580, 2585 may be connected to receive different levels of electroplating power to compensate for the variations in the resistance of the plated film. An advantage of the close proximity of the anodes 2585 to the wafer 25 is that it provides a high degree of control of the radial film growth resulting from each anode.

Anodes 2580, 2585 may be consumable, but are preferably inert and formed from platinized titanium or some other inert conductive material. However, as noted above, inert anodes tend to evolve gases that can impair the uniformity of the plated film. To reduce this problem, as well as to reduce the likelihood of the entry of bubbles into the main processing chamber 2505, processing container 35 includes several unique features. With respect to anode 2580, a small fluid flow path 2590 is provided between the underside of anode 2580 and antechamber 2510. This results in a Venturi effect that causes the electroplating solution proximate the surfaces of anode 2580 to be drawn into antechamber 2510 and, further, provides a suction flow that affects the uniformity of the impinging flow at the central portion of the surface of the wafer. Gas bubbles forming at the surfaces of anode 2580 are thus swept into antechamber 2510 and are prevented from entering main chamber 2505. Rather than entering main chamber 2505 where they would disturb the boundary layer conditions at the surface of wafer 25, the gas

bubbles enter antechamber 2510 and exit the gas outlet at the upper region of antechamber 2510. The Venturi flow path 2590 may be shielded to prevent any large bubbles originating from outside the chamber from rising through region 2590. Instead, such bubbles enter the bubble-trapping region of the antechamber 2510. Similarly, electroplating solution sweeps across the surfaces of anodes 2585 in a radial direction toward fluid outlet 2570 to remove gas bubbles forming at their surfaces. Further, the radial components of the fluid flow at the surface of the wafer assists and sweeping gas bubbles therefrom.

The foregoing reactor design effectively de-couples the fluid flow from adjustments to the electric field. This occurs due to the absence of a diffuser disposed between the anode and the cathode (workpiece). Further, the use of multiple anodes contributes to this result as well. An advantage of this approach is that a chamber with nearly ideal flow for electroplating and other processes (i.e., a design which provide substantial uniform diffusion layer across the wafer). may be designed that will not be degraded when electroplating or other process applications require significant changes to the electric field.

There are numerous processing advantages with respect to the illustrated flow through the reactor chamber. As illustrated, the flow through the various system components is directed away from the wafer surface and, as such, there are no jets of fluid created to disturb the

uniformity of the diffusion layer. Although the diffusion layer may not be perfectly uniform, any non-uniformity will be relatively gradual as a result.

As is also evident from the foregoing reactor design, the flow that is normal to the wafer has greater a magnitude near the center of the wafer and creates a dome-shaped meniscus. The dome-shaped meniscus assists in minimizing bubble entrapment as the wafer or other workpiece is lowered into the processing solution (here, the electroplating solution). The flow pattern resulting in the dome-shaped meniscus is influenced by the Venturi flow at the bottom of the chamber 2505. This flow at the bottom of the main chamber 2505 influences the flow at the centerline thereof. The centerline flow velocity is otherwise difficult to implement and control. However, the strength of the Venturi flow provides a non-intrusive design variable that may be used to affect this aspect of the flow.

A still further advantage of the foregoing reactor design is that it assists in preventing bubbles that find their way into the main chamber from reaching the wafer. To this end, the flow pattern is such that the solution travels downward just before entering the main chamber. As such, bubbles remain in the antechamber and escape through holes at the top thereof. Further, bubbles are prevented from entering the main chamber through the Venturi flow path through the use of the shield that covers the Venturi flow path (see description of the embodiment of the reactor illustrated in FIGURES 30-32). Still further, the upward sloping inlet path (see FIGURE

32 and appertaining description) to the antechamber prevents bubbles from entering the main chamber through the Venturi flow path.

There are also advantages associated with the electric field in the foregoing reactor design. Multiple concentric anodes are used so that a uniform film can be plated by making adjustments to the current passing through each anode. Generally, the more resistive the plated film, the more the magnitude of the current at the central anodes should be increased to yield a uniform film. Some further reasons for adjusting the electric field include changes to the following:

- seed layer thickness;
- open area of plating surface (pattern wafers, edge exclusion);
- final plated thickness;
- bath conductivity, metal concentration; and
- plating rate.

The particular reactor embodiment disclosed herein is readily adapted to compensate for the foregoing changes.

FIGURES 30-32 illustrate a specific construction of a complete processing chamber assembly 2610. As illustrated, assembly 2610 is comprised of the processing container 35 shown in FIGURE 29 along with a corresponding exterior cup 2605. Processing container 35 is

disposed within exterior cup 2605 to allow exterior cup 2605 to receive spent electroplating solution that overflows from the processing container 35. A flange 2615 extends about the assembly 2610 for securement with, for example, the frame of the corresponding tool.

With particular reference to FIGURES 31 and 32, the flange of the exterior cup assembly 2605 is formed to engage or otherwise accept rotor portion 75 of head assembly 25 and allow contact between the wafer 25 and the processing solution, such as electroplating solution, in the main chamber 2505. The exterior cup assembly 2605 also includes a main cylindrical housing 2625 into which a drain cup member 2627 is disposed. The drain cup member 2627 includes an outer surface having channels 2629 that, together with the interior wall of housing 2625, form one or more helical flow chambers 2640 that serve as an outlet for the processing solution. Electroplating solution overflowing a weir member 2739 at the top of processing cup 35 drains through the helical flow chambers 2640 and exits an outlet (not illustrated) where it is either disposed of or replenished and re-circulated. This configuration is particularly suitable for systems that include fluid re-circulation since it assists in reducing the mixing of gases with the processing solution thereby further reducing the likelihood that gas bubbles will interfere with the uniformity of the diffusion layer at the workpiece surface.

In the illustrated embodiment, antechamber 2550 is defined by the walls of a plurality of separate components. More particularly, antechamber 2550 is defined by the interior walls of

drain cup member 2627, an anode support member 2697, the interior and exterior walls of a mid-chamber member 2690, and the exterior walls of flow guide 2550.

FIGURE 31 illustrates the manner in which the foregoing components are brought together to form the reactor. To this end, the mid-chamber member 2690 is disposed interior of the drain cup member 2627 and includes a plurality of leg supports 2692 that sit upon a bottom wall thereof. The anode support member 2697 includes an outer wall that engages a flange 630 that is disposed about the interior of drain cup member 2627. The anode support member 2697 also includes a channel 2705 that sits upon and engages an upper portion of flow guide 2550, and a further channel 2710 that sits upon and engages an upper rim of nozzle assembly 2530. Mid-chamber member 2690 also includes a centrally disposed annular receptacle 2715 that is dimensioned to accept the lower portion of nozzle assembly 2530. Likewise, an annular channel 2725 is disposed radially exterior of the annular receptacle 2715 to engage a lower portion of flow guide 550.

In the illustrated embodiment, the flow guide 2550 is formed as a single piece and includes a plurality of vertically oriented slots 2670. Similarly, the nozzle assembly 2530 is formed as a single piece and includes a plurality of horizontally oriented slots that constitute the nozzles 2555.

The anode support assembly 2697 includes a plurality of annular grooves that are dimensioned to accept corresponding annular anode assemblies 2785. Each anode assembly 2785 includes an anode 2585 (preferably formed from platinized titanium or in other inert metal) and a conduit 2730 extending from a central portion of the anode 2585 through which a metal conductor may be disposed to electrically connect the anode 2585 of the assembly 2785 to an external source of electrical power. Conduit 2730 is shown to extend entirely through the reactor assembly 2610 and is secured at the bottom thereof by a respective fitting 2733. In this manner, anode assemblies 2785 effectively urge the anode support member 2697 downward to clamp the flow guide 2550, nozzle member 2530, mid-chamber member 2690, and drain cup member 2627 against the bottom portion 2737 of the housing assembly 2605. This allows for easy assembly and disassembly of the reactor 2610.

The illustrated embodiment also includes a weir member 2739 that detachably snaps or otherwise easily secures to the upper exterior portion of anode support member 2697. As shown, weir member 2739 includes a rim 2742 that forms a weir over which the processing solution flows into the helical flow chamber 2640. Weir member 2739 also includes a transversely extending flange 2744 that extends radially inward and forms an electric field shield over all or portions of one or more of the anodes 2585. Since the weir member 2739 may be easily removed and replaced, the reactor assembly 2610 may be readily reconfigured and adapted to provide

different electric field shapes. Such differing electrical field shapes are particularly useful in those instances in which the reactor must be configured to process more than one size or shape of a workpiece.

The anode support member 2697, with the anodes 2727 in place, forms the contoured wall 2560 and slanted wall 2565 that is illustrated in FIGURE 29. As noted above, the lower region of anode support member 2697 is contoured to define the upper interior wall of antechamber 2510 and preferably includes one or more gas outlets 2665 that are disposed therethrough to allow gas bubbles to exit from the antechamber 2510 to the exterior environment.

With particular reference to FIGURE 32, inlet 2515 is defined by an inlet fluid guide, shown generally at 2810, that is secured to the floor of drain cup member 2627 by one or more fasteners 2815. Inlet fluid guide 2810 includes a plurality of open channels 2817 that guide fluid received at inlet 2515 to an area beneath mid-chamber member 2690. Channels 2817 of the illustrated embodiment are defined by upwardly angled walls 2819. Electroplating solution exiting channels 2817 flows therefrom to one or more further channels 2821 that are likewise defined by walls that angle upward.

Central anode 2580 includes an electrical connection rod 2581 that proceeds to the exterior of the reactor assembly 2610 through central apertures formed in nozzle member 2550, drain cup member 2627 and inlet fluid guide2810. The small fluid regions shown at 2590 in

FIGURE 29 are formed in FIGURE 32 by vertical channels 2823 that proceed through drain cup member 2627 and the bottom wall of nozzle member 2550. The vertical channels 2823 of the drain cup member 2627 are separated from the vertical channels 2823 at the bottom wall 2825 of nozzles member 2550 by an intermediate chamber 2827 that is defined by the exterior portion of bottom wall 2825 and the interior wall at the bottom of drain cup member 2627. As illustrated, the exterior portion of bottom wall 2825 extends at a downward angle from a central region thereof. This construction assists in preventing bubbles from entering the main chamber 2505 since any bubbles reaching vertical channel 2823 of drain cup member 2627 will proceed into chamber 2827 and flow to the upper portions thereof proximate connection rod 2581 without entering main chamber 2505.

Numerous modifications may be made to the foregoing system without departing from the basic teachings thereof. Although the present invention has been described in substantial detail with reference to one or more specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the scope and spirit of the invention as set forth in the appended claims.